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B_d mixing measurements with the *BABAR* detector

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Abstract

The $B^0\overline{B}^0$ oscillation frequency Δm_d has been measured with the *BABAR* detector at the PEP-II asymmetric B factory with different experimental techniques. The discussion here is focused on the recent simultaneous measurement of Δm_d and τ_{B^0} with exclusively reconstructed $B^0 \to D^{*-}\ell^+\nu_l$ decays, based on 23 million $B\bar{B}$ pairs collected by *BABAR* . The measurements of Δm_d with fully reconstructed hadronic decays and with dilepton events are also reviewed. The average *BABAR* result is $\Delta m_d = 0.500 \pm 0.008 \pm 0.006\ ps^{-1}$.

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1 Introduction

Particle-antiparticle oscillations or mixing, has been observed in the neutral $B\bar{B}$ meson system almost fifteen years ago [1]. This quantum-mechanical behavior is originated by the flavor eigenstates B^0 and $\bar{B}^0$ not being Hamiltonian eigenstates. The frequency of the oscillation is the mass difference between the mass eigenstates, Δm_d. In the Standard Model, $B^0\bar{B}^0$ mixing occours through second-order weak diagrams involving the exchange of up-type quarks, with the top quark contributing the dominant amplitude. A measurement of Δm_d is therefore sensitive to the value of the Cabibbo-Kobayashi-Maskawa matrix element V_{td} [2]. The oscillation frequency Δm_d has been measured with both time-integrated and time-dependent techniques [3]. Asymmetric B factory experiments like *BABAR* can perform high statistics time dependent measurements of Δm_d.

2 Measurements of Δm_d with the *BABAR* detector

The *BABAR* detector [4] collects data at the PEP-II asymmetric e^+e^- collider operated at or near the $\Upsilon(4S)$ resonance. $B\bar{B}$ pairs from $\Upsilon(4S)$ decay move along the high-energy beam direction (z) with a nominal Lorentz boost $< \beta\gamma >= 0.55$. Therefore, the two B decays vertices are separated by about 260 μm on average. The two B mesons are produced in a coherent P-wave state and their proper decay-time difference Δt distribution is governed by the following probabilities to observe *mixed*(-) or *unmixed*(+) events:

$$Prob(B^0\bar{B}^0 \rightarrow B^0\bar{B}^0, B^0B^0 or \bar{B}^0\bar{B}^0) \propto \\ e^{-\frac{|\Delta t|}{\tau_{B^0}}}(1 \pm cos\Delta m_d \Delta t). \tag{1}$$

Therefore, a measurement of Δt together with the identification of the b-flavor of both B mesons at their time of decay, allows to observe the oscillations and to extract Δm_d.

In the following sections the simultaneous measurement of Δm_d and τ_{B^0} with exclusively reconstructed $B^0 \rightarrow D^{*-}\ell^+\nu_l$ decays [5], the measurement of Δm_d with fully reconstructed hadronic B^0 decays [6] and with inclusively reconstructed dilepton events [7], will be discussed.

3 Measurement of Δm_d and τ_{B^0} with exclusively reconstructed $B^0 \rightarrow D^{*-}\ell^+\nu_l$ decays

The analysis is based on a sample of approximately 14,000 exclusively reconstructed $B^0 \rightarrow D^{*-}\ell^+\nu_l$ decays selected from 23 million $B\bar{B}$ pairs recorded in the years 1999-2000 by *BABAR* . The purity of the sample is 65-89% depending on the decay mode of the $\bar{D}^0$ from the D^{*-}.

One of the two B produced by the $\Upsilon(4S)$ decay is reconstructed in the semileptonic mode and the charge of the final-state particles identifies the flavor of the B. D^{*-} candidates are reconstructed using the decay $D^{*-} \rightarrow \bar{D}^0\pi^-$, while $\bar{D}^0$ candidates are reconstructed in the modes $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$ and $K^0_s\pi^+\pi^-$. D^{*-} candidates are then combined with oppositely charged high-energy electrons or muons in the event and the $D^{*-}\ell^+$ pair is required to pass kinematic cuts that enhance the contribution of $B^0 \rightarrow D^{*-}\ell^+\nu_l$ decays. The B mass and energy cannot be reconstructed because of the presence of the neutrino, thus the distribution δm of the difference between the D^{*-} and the D^0 masses is used to select B candidates. The distribution of δm for events passing the selection criteria in the muon sample is shown in Figure 1.

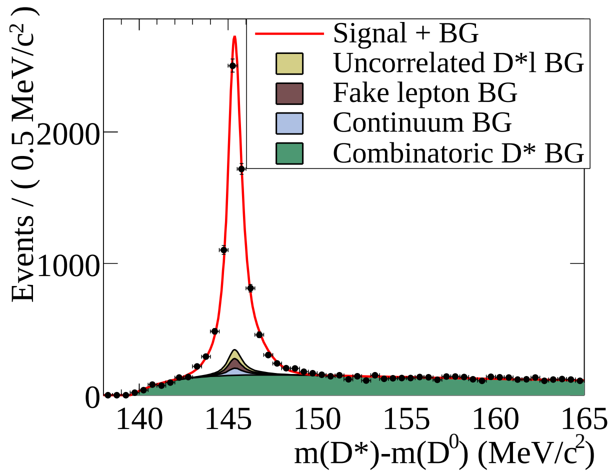

Figure 1: δm distribution for events passing all selection criteria for $B^0 \to D^{*-}\ell^+\nu_l$ decays with a muon candidate. The points correspond to the data. The curve is the result of a fit. The shaded distributions correspond to the four types of background (BG) described in the text.

There are two types of background with respect to the δm distribution: combinatoric background and peaking background. Combinatoric background is due to events with a mis-reconstructed D^{*-} and does not peak in the δm distribution. Peaking background is due to $B\bar{B}$ events with misidentified leptons or uncorrelated true leptons, and continuum events. The δm distribution of the peaking background is the same as the distribution of the signal. Several control samples are selected to characterize the various backgrounds in both the fraction and the time distribution.

All the charged tracks in the event, except the reconstructed tracks from the $D^{*-}\ell^+$ pair, are used to identify the flavor of the other B (referred to as B_{tag}). There are five types of tagging categories. The first two tagging categories rely on the presence of a prompt lepton or charged kaons in the event, whose charge is correlated with the b-flavor of the decaying B. The other three categories exploit a variety of inputs (e.g. slow pions, momentum of the track with the maximum center-of-mass momentum) with a neural network technique.

The difference Δt between the two B decay times is determined from the measured separation $\Delta z = z_{D*l} - z_{tag}$ along the beam axis between the $D^{*-}\ell^+$ vertex and the B_{tag} vertex. The measured Δz is converted into Δt with the known $\Upsilon(4S)$ boost according to the relation $\Delta z = c\beta\gamma\Delta t$ which neglects the small B momentum in the $\Upsilon(4S)$ frame. The resolution on the $D^{*-}\ell^+$ vertex is about 70 μm while the resolution on the B_{tag} vertex is about 160 μm.

Each tagging category i has a probability w_i of incorrectly assigning the flavor of the B_{tag} and there is a limited precision on the Δt measurement. These two experimental complications affect the Δt distribution of Equation 1 which becomes:

$$Prob(B^0\bar{B}^0 \to B^0\bar{B}^0, B^0B^0 or \bar{B}^0\bar{B}^0) \propto$$
$$\mathcal{R}(\delta t; \hat{a}) \otimes e^{-\frac{|\Delta t|}{\tau_{B0}}}(1 \pm (1-2w_i)cos\Delta m_d \Delta t).$$

The function $\mathcal{R}(\delta t; \hat{a})$ is the resolution function which parametrizes the response to Δt of the detector, $\delta t = \Delta t_{meas}$ - Δt_{true} and $\hat{a}$ is a set of parameters. The final Δt distribution also includes terms for each relevant background source.

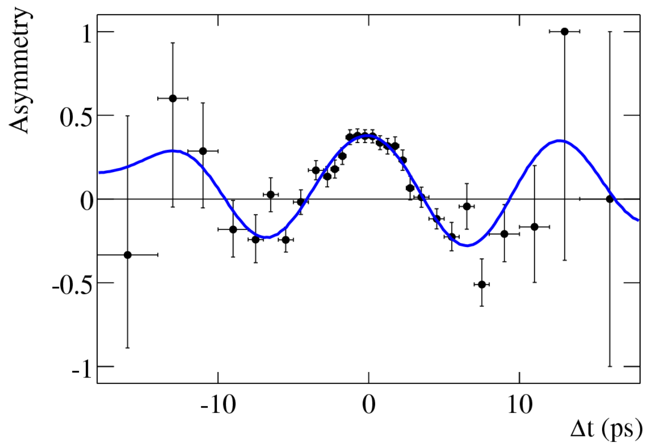

Figure 2: Mixing asymmetry plot for a 80% pure $B^0 \to D^{*-}\ell^+\nu_l$ sample. The dots are the data and the curve is the projection of the fit result.

The oscillation frequency Δm_d and the lifetime τ_{B^0} are determined simultaneously with an unbinned maximum likelihood fit to the measured Δt distribution. Note that other mixing measurements fix τ_{B^0} to the world average and this is the source of the dominant systematic error. Also the resolution, the fraction of charged B, the mistag and the background parameters are floated in the fit. The results are: $\Delta m_d = 0.492 \pm 0.018(stat) \pm 0.013(syst)\ ps^{-1}$ and $\tau_{B^0} = 1.523^{+0.024}_{-0.023}(stat) \pm 0.022(syst)\ ps$. The correlation between Δm_d and τ_{B^0} is -0.22. A correction is applied to both Δm_d and τ_{B^0} which takes into account selection and fit biases. The uncertainty on such a correction is the dominant systematic error. Other *BABAR* measurements for τ_{B^0} can be found in [8] and [9]. Figure 2 shows the mixing asymmetry defined as the difference between the number of unmixed and mixed events over their sum as a function of Δt.

4 Measurement of Δm_d with fully reconstructed B^0 hadronic decays

The analysis is based on ∼6300 B^0 selected from 32 million $B\bar{B}$ pairs. The B^0 are reconstructed in the flavor eigenstates $D^{*-}\pi^+$, $D^{*-}\rho^+$, $D^{*-}a_1^+$, $J/\psi K^{*0}$ and the purity of the selected sample is about 86%. B^0 candidates are selected using the difference between the energy of the candidate and the beam energy $\sqrt{s}/2$ in the center of mass frame, and the beam energy substituted mass, calculated from $\sqrt{s}/2$ and the reconstructed momentum of the B.

The tagging algorithm and the tagging vertex reconstruction technique are described in the previous section. Δm_d is extracted with an unbinned maximum likelihood fit to the Δt distribution (obtained from Δz as described in the previous section) where also all the mistag probabilities and the resolution parameters are floated. The result is $\Delta m_d = 0.516 \pm 0.016(stat) \pm 0.010(syst)\ ps^{-1}$, the dominant systematic error being the uncertainty on τ_{B^0} which is fixed in the fit.

5 Measurement of Δm_d with inclusive dilepton events

The analysis is based on 23 million $B\bar{B}$ pairs. The measurement technique consists in the identification of events containing two high energy leptons from semileptonic decays of B mesons. The flavor of the B mesons at the time of their decay is determined by the charge of the leptons. About 99000 events are selected, ~ 55 % of them being B^+B^- events which are not removed by the event selection criteria. Another non negligible background is due to leptons from the $b \to c \to l$ decay chain (~ 13 %) which are also the main source of wrongly tagged events. The difference of the z coordinates of the two B decay vertices Δz is determined using the two lepton tracks and a beam spot constraint. Δt is then obtained from Δz as described in section 3. A binned maximum likelihood fit is used to extract Δm_d together with the resolution parameters, the fraction of charged B and some of the background fractions and parameters. The result is $\Delta m_d = 0.493 \pm 0.012(stat) \pm 0.009(syst)$ ps^{-1}. The dominant systematic error is due to the uncertainty on B^0 and B^+ lifetimes which are fixed in the fit.

6 Conclusions

The oscillation frequency Δm_d of the $B^0\overline{B}^0$ system has been measured by the *BABAR* experiment with different experimental techniques. The combined *BABAR* result is $\Delta m_d = 0.500 \pm 0.008 \pm 0.006$ ps^{-1}. The corresponding precision is 2% to be compared with the world average precision which is 1.2 %.

References

[1] UA1 Collaboration, C.Albajar *et al.,* Phys.Lett. **B186**, 247 (1987); ARGUS Collaboration, H. Albrecht *et al.,* Phys. Lett. **B192**, 245 (1987).

[2] N.Cabibbo, Phys.Rev.Lett. **10**, 531 (1963); M.Kobayashi and T.Maskawa, Prog. Th. Phys. **49**, 652 (1973).

[3] D.E. Groom *et al.,* Eur. Phys. Jour. **C15**, 1 (2000);

[4] The *BABAR* Collaboration, B. Aubert *et al.,* Nucl. Instrum. Meth. **A479**, 1 (2002).

[5] The *BABAR* Collaboration, B. Aubert *et al.,* hep-ex/0207071, 2002.

[6] The *BABAR* Collaboration, B. Aubert *et al.,* Phys. Rev. Lett. **88**, 221802 (2002).

[7] The *BABAR* Collaboration, B. Aubert *et al.,* Phys. Rev. Lett. **88**, 221803 (2002).

[8] The *BABAR* Collaboration, B. Aubert *et al.,* Phys. Rev. Lett. **89**, 011802 (2002).

[9] The *BABAR* Collaboration, B. Aubert *et al.,* Phys. Rev. Lett. **87**, 201803 (2001).